DESIGN OF WIND TUNNEL (FLUID FLOW ANALYSIS)

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ABSTRACT

A low speed wind tunnel was design and fabricate. The project covered the process of design and fabrication of the small wind tunnel. In completing this project, a computer aided drawing (CAD) called Solid Work is use to design the wind tunnel. Experiment conducted after build the wind tunnel to find drag coefficient of a sphere. The drag force on a sphere in an air stream was measured at various free stream velocities below 100 m/s. This was done in a low speed wind tunnel using an integral balance system to measure the drag force and a Pitot tube and to measure the velocity. The raw data were processed according to classical equations of fluid mechanics which define the drag coefficient. An impression of fluid field flow around a sphere is also capture using white smoke. Method of analysis the flow in test section was shown by using strings. The experimental results are compared to published results over the range tested.

ABSTARK

Terowong angin subsonik direka dan dibina. Projek ini merupakan proses reka bentuk dan fabrikasi terowong angin. Rekaan terowong angin dilukis dengan bantuan computer aided drawing (CAD) iaitu Solid Work. Experimen dijalankan untuk mencari pekali rintangan sfera diuji di terowong angin ini. Daya ringtangan suatu sfera diukur pada variasi kelajuan bawah 100 m/s. Ia boleh diuji melalui terowong angin dengan menggunakan sistem imbangan bagi mengukur daya ringtangan dan tiub pitot digunakan untuk mengukur kelajuan. Data diambil dan diproses dengan rumus cecair mekanik bagi mendpatkan nombor pekali ringtangan. Gambaran pegerakan udara pada sfera ditangkap dengan menggunakan kamera. Asap digunakan untuk melihat pegerakan udara pada sfera. Kaedah tali benang juga digunakan untuk menganalisis pegerakan udara di dalam kebuk ujian terowong angin. Keputusan experimen dibandingkan dengan keputusan theori di buku.

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LIST OF ABBREVIATIONS

F_D	Drag force in N
C_D	Drag coefficient
Re	Reynolds number
D	Diameter of sphere in m
ρ	Density of air in kg/m^3
u_∞	Velocity of air stream in m/s
P	Atmospheric pressure in N/m^2
Δp	Pressure difference in manometer in N/m^2
Δh	Difference in heights of liquid in manometer in mm
T	Atmospheric temperature in Kelvin
μ	Viscosity of air in kg/m-hr
ρ_o	Density of oil in manometer in kg/m^3

CHAPTER 1

INTRODUCTION

1.1 WIND TUNNEL

1.1.1 History

Discovery and development by experimental means has been its lifeblood, extending all the way back to George Cayley. In 1804, he built a whirling arm apparatus for testing aerofoil. This was simply lifting surface (aerofoil) mounted on the end of long road, which was rotated at some speed to generate a flow of an air over the aerofoil. In modern aerospace engineering, the workhorse for such experiments has been predominantly the wind tunnel, so much such that today most aerospace industries, government and university laboratories have a complete spectrum of wind tunnels ranging from low subsonic to hypersonic speeds.[19]

In other side, the enormous advances in computer technology both computer hardware and numerical methods have possible to model the fluid flow more accurate. The setup of model can be performed easily. This question comes up, whether theoretical calculation could one day substitute wind tunnel tests altogether. At present the computational method can surely predict the simple models such as real flow in wind tunnel still requires a large time consuming therefore it is still difficult and expensive. In addition the computational method still provides the calculation of drag not satisfactory compare to the wind tunnel results. Thus, for aeronautical developments wind tunnel testing will remain predominant in foreseeable future. [19]

However, besides for aerospace applications, the experimental techniques using wind tunnel also have broad applications in many other branches of science and engineering such in automotive and architecture. For automotive applications, the experimental techniques in wind tunnel may be used to predict aerodynamic characteristics of designed racing cars and other high performance vehicles. For architecture applications, the wind tunnel may be used to simulate the pollutant condition happened around buildings in the city. [19]

The scientists work in experimental techniques of wind tunnel is somewhat different than of engineers. Scientists are engaged in fundamental research, engineers make experiments in course of the project. Their detailed investigations are aiming at the improvement of basic knowledge about the physics of fluid flow. The results may provide the foundation of new theories, or are used to evaluate or scrutinize existing theories or supplement them. Quite often they don't appear have any direct bearing on practical engineering problems. For engineering purposes test techniques to be employed during project work must be proven standard, reliable, quick to use and possibly cheap. The test results must be provide comprehensive information such as the aerodynamic characteristics of a tested aerodynamic configuration. Details of the flow are studied just with the particular purpose of deducing improvements for the configuration. In general the test results must be comprising a proof, that the design targets are being met and safe. [19]

1.1.2 Wind tunnel

A wind tunnel is a device designed to generate air flows of various speeds through a test section. Wind tunnels are typically used in aerodynamic research to analyze the behaviour of flows under varying conditions, both within channels and over solid surfaces. Aerodynamicists can use the controlled environment of the wind tunnel to measure flow conditions and forces on models of aircraft as they are being designed. Being able to collect diagnostic information from models allows engineers to inexpensively tweak designs for aerodynamic performance without building numerous fully-functional prototypes. In the case of this project, the wind tunnel will serve as an educational and research tool to analyze basic flow principles. [2]

The wind tunnel provides great benefits for aerodynamic tests compared to free flight testing, that is:

i. Specified flow condition such as Mach number and incidence can be achieved sustained much easier in a wind tunnel.
ii. Dangerous, uncontrollable flight condition may safely investigate in wind tunnel.
iii. Data acquisition and processing is simpler with direct connection to ground based equipment.

The main disadvantage of wind tunnel is that it is seldom possible to reproduce the condition of full scale motion exactly. This is mainly due to the use of scaled models for reason of tunnel cost and power consumption. [2]

1.1.3 Fluid flow

For centuries, fluid flow researchers have been studying fluid flows in various ways, and today fluid flow is still an important field of research. The areas in which fluid flow plays a role are numerous. Gaseous flows are studied for the development of cars, aircraft and spacecrafts, and also for the design of machines such as turbines and combustion engines. Liquid flow research is necessary for naval applications, such as ship design, and is widely used in civil engineering projects such as harbour design and coastal protection. In chemistry, knowledge of fluid flow in reactor tanks is important; in medicine, the flow in blood vessels is studied. Numerous other examples could be mentioned. In all kinds of fluid flow research, visualization is a key issue [3]

1.2 PROBLEM STATEMENT

This paper will focus primarily on the fabrication process of small scale wind tunnel, flow visualization analysis on an object and calculation of drag coefficient of an object through experiment.

1.3 OBJECTIVES

i) To develop a small scale wind tunnel for educational and research purpose.
ii) To get an impression of fluid flow around a scale model of a real object.
iii) To calculate the drag coefficient of object design.

1.4 PROJECT SCOPES

i) To find the design fundamental for a small wind tunnel.
ii) Make the research for small wind tunnel background and contruction.
iii) To find the best material to be used and estimate the cost for model construction.
iv) To study the flow visualazation of an object design.
v) To determine the drag coefficient of an object design.

CHAPTER 2

LITERATURE REVIEW

2.1 FLUID MECHANICS TERMINOLOGY

Drag is the component of force acting on a body that is projected along the direction of motion. Both shear forces and pressure induce drag on a body in motion. Shear forces, known as skin friction drag, are more significant in streamlined objects, while the pressure drag is more significant in blunt objects [14] Figure 2.1 shows the net drag force acting on a cylinder.

The drag force is often non-dimensionalized as a function of Reynolds number. This is then referred to as the drag coefficient (Eqn2.1). Similarly, the pressure acting on each differential element of an object may be normalized by the dynamic free stream pressure $\frac{1}{2}\rho v_{\infty}^{2}$ to obtain the pressure coefficient (Eqn2.2). This quantity may also be rewritten as the reduced pressure coefficient (Eqn2.3).

$$C_D = \frac{F_D}{\frac{1}{2}\rho v^2 A} \tag{2.1}$$

$$C_P = \frac{\Delta p}{\frac{1}{2}\rho v^2} \tag{2.2}$$

$$C_P = \frac{q}{q_\infty} \tag{2.3}$$

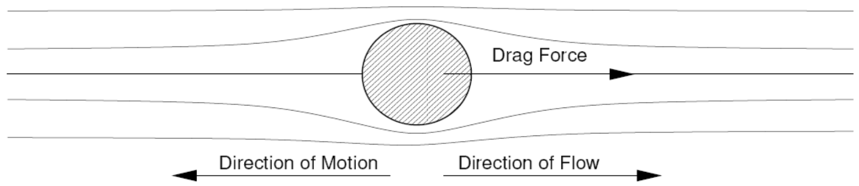

Figure 2.1: Drag force on sphere

2.2 TESTING PARAMETER

2.2.1 Flow consideration

In wind tunnel testing, the real configurations such an aircraft and its components are usually scaled down to become the corresponding small size model that can be installed in test section of wind tunnel. In order to obtain similar flow condition in the wind tunnel as free flight at full scale, it requires more than just to ensure geometrical similarity of the model. One also has to take care that forces produced by flow are in the same relationship to each other. [14]

In fluid dynamics there exist a number of similarity parameters. They represent the relation of the various forces in a fluid flow such as:

i. Inertia forces = ρV^2
ii. Viscous forces = $\mu V/I$
iii. Compression forces = ρa^2
iv. Gravity forces = $\rho g I$

All forces here are taken per unit area. Similarity parameters are formed by relating the various forces to the inertia force. They include Reynolds number, Mach number and Froud number.[2]

2.2.2 Reynolds number

The Reynolds (Re) number is a quantity which engineers use to estimate if a fluid flow is laminar or turbulent. This is important, because increased mixing and shearing occur in turbulent flow. [2]

The Reynolds number is calculated using mean velocity, pipe diameter, density, and viscosity, and is valid for any fluid. The Reynolds number is also dependent upon the geometry of the pipe, as well as the roughness of the walls. Analysis of the Reynolds number using the dimensionless forms of the Navier Stokes equations reveals that the Reynolds number is really a ratio of inertial forces to vicious forces. As of yet, no successful analytic methods for determining Reynolds numbers have been developed due largely to the difficulty associated with predicting turbulent flow, and so Reynolds numbers for flow through pipes or around immersed objects must be determined experimentally. We define Reynolds number as

$$Re = \frac{\rho L_{char} V}{\mu} \tag{2.4}$$

The L_{char} is the length characteristic of geometry and V is a velocity appropriate for the flow. Osborn Reynolds identifies this parameter in1883 as being important in fluid mechanics. If Re < 2100 it is said to be in laminar and Re > 4000 is in turbulent state. [2]

2.2.3 Mach number

This number relates the compressibility to the inertia forces. Its similarity is important when noticeable variations of density and temperature occur at high flow velocities.[9] The Mach number is defined as:

$$\mathrm{Ma} = \frac{V}{a} \tag{2.5}$$

2.2.4 Froud number

This number relates the gravity to the inertia forces. Its similarity is important when gravity forces are involved. This is important for model drop tests. It is also interesting when waves occur such when the hydrodynamic analogy is used to simulate supersonic waves.[9] The Froude number is defined as:

$$F_r = \frac{V}{\sqrt{gI}} \tag{2.6}$$

When the two flow parameters such as Mach number and Reynolds number and the objects are geometrically similar, the flows will be dynamically similar and the results from investigating one flow should be transferable to the other. [2]

For example suppose want to improve the design of a golf ball. You want the ball to have as small a drag force as possible. If the golf ball 0.04 meter in diameter, travel at 25m/s and at sea level air, then it has Reynolds number of 68,200 based on its diameter and its travelling at Mach number of 0.06. You can make a large model of a golf ball, say 0.2 in diameter and tested it in your wind tunnel as long as you match the Reynolds number. Mach number is so low and can be ignore, there is no significant compressibility effects in the flow field. In this case you should you should run your wind tunnel with a free stream velocity of 5m/s to match Reynolds number. Under these conditions the boundary layer on the golf ball and the wake behind it will be perfectly to scale. If the golf ball in flight has a boundary layer of 0.001 meter thick at one point, then the model will have boundary layer of 0.005 meter thick its corresponding point. You are free to test all sort of dimple design and the drag coefficients measure will be the sane drag coefficient the ball would experience at 25 m/s. [2]

2.2.5 Boundary layer

Boundary layers are regions of fluid located immediately adjacent to an immersed object or wall in which flow velocities are governed by viscous forces. Drag forces and most of the heat exchange experienced by the object are due to fluid in this region. Boundary layers typically begin as a very thin region of laminar flow that thickens with increasing Reynolds numbers and then gradually transitions to a turbulent layer flowing over a viscous sub layer. Flow outside of the boundary layer is independent of Reynolds number criteria. Figure 2.2 shows boundary layer of a flat plate. [21]

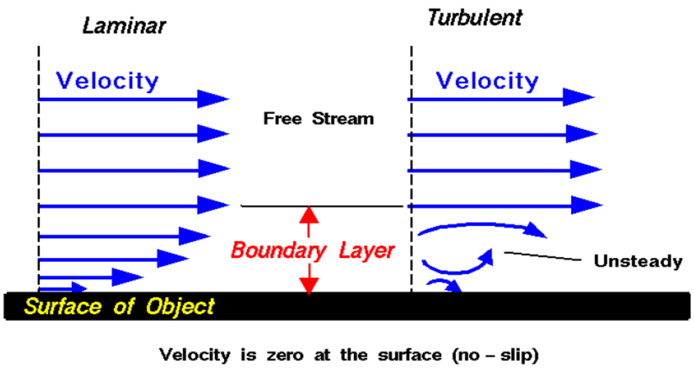

Figure 2.2: Velocity profile for boundary layers along the wall

2.3 WIND TUNNELS

Wind tunnel is a device used to investigate an interaction between solid body flows in wind tunnel can be performed in term of:

i. Monitoring physical flow phenomenon such as laminar, tuberlent and separation flows, vortex and shock wave.
ii. Measuring aerodynamic quantities such as pressure, skin friction, lift, drag and moments.

In order to monitor the flow phenomenon and measure aerodynamic quantities, engineers require measuring equipments and measurement techniques. One experimental aerodynamic problem can be solved by some different measurement techniques. In addition, for a special problem of experimental aerodynamic sometimes requires a specific wind tunnel construction. [9]

The aerodynamic problems can be distinguished in two matters:

i. External aerodynamics, that is solid body immersed in the flow such as around wings or aerofoils.
ii. Internal aerodynamics that is flow moving inside the body such as ducts, pipes and turbines.

2.4 CLASSIFICATION OF WIND TUNNEL

2.4.1 Based on speed range

The most appropriate classification of wind tunnels is by the speed range they cover. The classification of wind tunnels based on the speed range includes:

i. Low speed wind tunnel

   The flow velocity in low subsonic wind tunnel is of the Mach number range of zero till 0.3. Viscous and inertial forces are dominant while compressibility effects are negligible.

ii. High speed wind tunnel

   The designation high speed usually includes high subsonic, transonic and low supersonic regimes, so that the range of the flow velocity for high speed wind tunnel is of Mach number between 0.3 and 1.4. Here, in principle, compressibility effects are of dominant importance. However, viscous effects also play an important part in particular when shock boundary layer intersection leads to flow separation.

iii. Supersonic wind tunnel

   The flow velocity in supersonic wind tunnel is the range of Mach number of 1.4 till 5.0. Compressibility effects are dominant. The pressure disturbance raises in the flow field propagating downstream.

iv. Hypersonic wind tunnel

   The flow velocity in hypersonic wind tunnel is of Mach number above 5.0. It is desired to allow real gas effects to occur. This requires that besides the high Mach number in test section also high total temperatures are provided.

> The high temperatures, which are linked with high pressures, yield vibration of the gas molecules, possibly causing dissociation and ionization. These are dominant features of hypersonic flows where the gas can no longer be treated as an ideal gas. [9]

With increasing Mach number the tendency to intermittent operating wind tunnels linked with an appropriate energy storage arrangement, becomes more and more compelling. However, for measurement of low subsonic flow, the continuously operating wind tunnel is more preferred. [9]

2.4.2 Based on flow circulation

The other wind tunnel classification based on flow circulation is divided into open circuit wind tunnel and closed circuit wind tunnel.

i. Open circuit wind tunnel

   Open circuit wind tunnel is first type of wind tunnel built. The tunnel is usually referred to as an Eiffel type. Such a wind tunnel consists of a nozzle, at test section, a diffuser and a driving unit. The principle work of this wind tunnel is a direct sucking of the atmospheric air lying outside of the wind tunnel brought into the tunnel settling chamber and continued to the end of the wind tunnel using a driving unit then the air is threw away to atmosphere. The position of driving units can be at the downstream end where the tunnel is operated as suction tunnel while otherwise it would be termed a blow down tunnel. The suction tunnel is more preferred in a design by a reason of airflow quality.

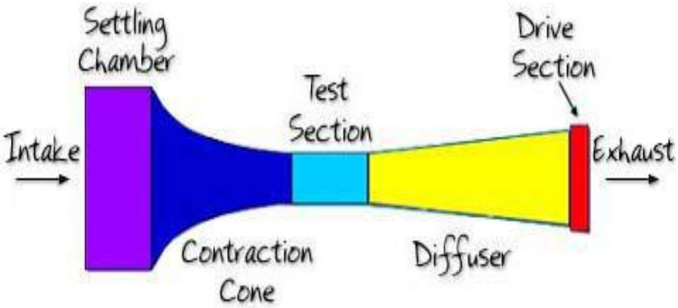

Figure 2.3: Open circuit wind tunnel

ii. Closed circuit tunnel

Closed circuit tunnel has been developed to reduce the amount of used energy. This tunnel is also called as Gottingen type. The principle work of this tunnel is by circulating the used airflow passing by the diffuser to the settling chamber using the connecting channel. The closed circuit tunnel consists of three types including single and double return. Of these, only the first is in general acceptance at present. In the double return arrangement, the particular air that scrapes along the wall of the return passages forms wakes in the centre of the jet and hence passes directly over the model. Unless the contraction ratio is large, this air is extremely tuberlent and tends to make the interpretation of the test data difficult. The fans are preferred attach on the connecting channel by reason of a protection from the model failure and of good from standpoint of fan efficiency.

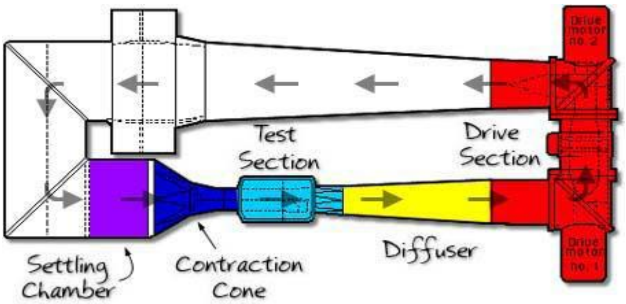

Figure 2.4: Closed circuit wind tunnel